Midterm outcome after the distal revascularization and interval ligation (DRIL) procedure

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Background: **The distal revascularization and interval ligation (DRIL) procedure has evolved as the optimal treatment for access-related hand ischemia despite concerns about its durability. This study was designed to review our institutional experience and objectively define its mid-term outcome.**

Methods: **A retrospective review of all patients undergoing the DRIL procedure was performed. The diagnosis of severe hand ischemia was made based primarily upon clinical presentation, but confirmed with noninvasive imaging in select cases. The DRIL conduit was selected based upon noninvasive imaging (vein conduit criteria: saphenous > arm; diameter ≥3 mm) and the proximal anastomosis was positioned ≥7 cm from the access anastomosis. The DRIL bypasses were followed in a graft surveillance protocol and remedial procedures performed as dictated by clinical or ultrasound scan findings.**

Results: **Sixty-four DRIL procedures were performed in 61 patients (age - 58 ± 13 standard deviation [SD], female – 62%, diabetic – 72%). The index access procedures included: autogenous brachiocephalic – 46%, autogenous brachiobasilic – 31%, autogenous brachioaxillary translocated femoral vein – 20%, other –3%. The precipitating symptoms were pain (25%), paresthesia (34%), motor dysfunction (24%), and tissue loss (17%); a pre-emptive DRIL was performed in 5 patients. The timing of the DRIL relative to the index access was dictated by the symptoms: <24 hrs – 19%; 1 day ≤ DRIL ≤7 days – 29%; 7 days ≤ DRIL ≤30 days – 8%; >30 days – 44%. Perioperative mortality rate was 3% and the complication rate was 22% (wound – 14%). The DRIL procedure relieved the ischemic symptoms in 78% of the cases (residual symptoms: paresthesia – 13%; pain – 5%; tissue loss – 4%; motor – 2%). The DRIL also resulted in significant ($P < .05$) increases in both the wrist/brachial index (WBI) and digital/brachial index (DBI) with the mean increases of 0.34 ± 0.26 and 0.41 ± 0.21, respectively. The primary DRIL patency rates (± standard error of the mean [SEM]) were 77 ± 8%, 74 ± 9%, and 71 ± 9% at 1 year, 3 years, and 5 years, respectively, while the corresponding secondary patency rates were 81 ± 7%, 76 ± 9%, and 76 ± 9%, and the survival rates were 71 ± 6%, 59 ± 7%, and 33 ± 9%. The index access procedure went on to mature sufficiently for cannulation in 68% of the cases when the DRIL was performed early (ie, <3 months from index access); all accesses functional at the time of the DRIL were used for dialysis throughout the perioperative period.**

Conclusion: **The DRIL procedure safely and effectively relieves the symptoms of severe access-related hand ischemia while preserving the access. The midterm results suggest that the DRIL bypasses are durable, although long-term graft surveillance may be justified given the observed failures. (J Vasc Surg 2008;48:926-33.)**

Hand ischemia is one of the most worrisome, non-fatal complications after upper extremity arteriovenous hemodialysis access procedures. The spectrum of ischemic symptoms ranges from a cool extremity (grade 1) to severe pain with tissue loss (grade 3)[1] and can lead to a dysfunctional hand requiring amputation, if untreated. Additionally, even patients addressed in a timely fashion can develop an ischemic neuropathy and persistent pain.[2] Unfortunately, access-related hand ischemia (aka, steal syndrome) is common with the incidence of any type of symptoms (ie, grades 1-3) ranging up to 20% and the more severe grades up to 10%.[3-6] A variety of clinical characteristics (eg, age, gender, diabetes, peripheral arterial occlusive disease)[4,6-9] and noninvasive laboratory criteria (eg, digital brachial index)[9] have been identified to help predict which patients are at risk. However, these preoperative predictors are collectively inadequate to determine when hand ischemia is inevitable.

The treatment options for patients with severe access-related hand ischemia include simple ligation or remedial procedures to improve blood flow to the hand while maintaining the access. Although it effectively reverses the ischemic symptoms, ligation sacrifices the access, and thereby limits a patient's longer-term access options. The various remedial procedures designed to salvage the access include limiting the flow through the access itself (ie, banding, lengthening, and anastomotic narrowing) or directly revascularizing the hand (ie, correction of inflow stenoses, distal revascularization, and distal revascularization with interval ligation (DRIL)). The DRIL procedure has evolved as the optimal remedial treatment and has been reported to effectively reverse the hand ischemia and preserve the ac-

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cess.[10-14] However, the overall published experience with this procedure is limited and concerns have been raised about the complexity of the procedure, the necessity of ligating the brachial artery, and the long-term patency rates of the bypass. This study was designed to review our institutional experience with the DRIL procedure and objectively define its midterm outcome.

METHODS

Experimental design. All patients undergoing any permanent hemodialysis access procedure at the University of Florida College of Medicine between Feb 1998 and Dec 2007 were identified by review of a prospectively maintained procedural database. The patients requiring definitive treatment (ie, ligation or DRIL) for severe (grades 2 or 3) access-related hand ischemia were then identified within the larger subset of access procedures. The complete hospital and outpatient medical records of those patients requiring a DRIL were then retrospectively reviewed and the perioperative and midterm outcomes determined. The study was approved by the Institutional Review Board (approval # 646-2007).

Clinical practice. Patients were evaluated and treated by a group of 8 board-certified or board-eligible vascular surgeons at a tertiary-care university medical center. All patients presenting for their initial permanent hemodialysis access procedure were evaluated using our prospectively validated algorithm designed to optimize the use of autogenous accesses.[15] Briefly, patients underwent both arterial and venous upper extremity imaging in the noninvasive vascular laboratory. A tentative operative plan was generated based upon the results of the noninvasive testing. Invasive imaging with arteriography and/or venography was used to confirm the initial plan in select patients with presumed significant occlusive disease. Criteria for a suitable outflow vein included a diameter ≥3 mm, a length spanning the forearm/arm and no ipsilateral central vein stenoses/occlusions. Criteria for a suitable inflow artery included no hemodynamically significant proximal stenoses and adequate diameter (ie, brachial ≥3 mm, radial ≥2 mm). The hierarchy of access procedures included autogenous radiocephalic > autogenous radiobasilic > autogenous brachiocephalic > autogenous brachiobasilic > prosthetic forearm/arm > translocated femoral/popliteal vein.[8]

The diagnosis of access-related hand ischemia was based primarily upon the clinical presentation and physical examination. Noninvasive imaging including upper extremity (ie, brachial/radial/ulnar/digit) pressures and the corresponding velocity waveforms were obtained in equivocal cases to confirm the diagnosis. Mild ischemia (grade 1) was treated expectantly with definitive treatment reserved for selected patients with moderate ischemia (grade 2) and all of those with severe ischemia (grade 3). Upper extremity arteriography with evaluation of the complete arterial tree from the aortic arch to the digits was used selectively to identify and correct any inflow lesions. Definitive treatment of persistent hand ischemia included access ligation or DRIL with the choice contingent upon patient comorbidities, type of access (autogenous vs prosthetic), onset of ischemia (early vs late), likelihood of autogenous access maturing sufficient for cannulation, and future access options.

The DRIL procedure was performed as previously described.[16] Briefly, the proximal anastomosis of the brachiobrachial artery bypass was placed ≥7 cm from the access anastomosis. The distal bypass anastomosis was placed immediately distal to that for the access and was configured end-side or end-end with ligation or transaction/oversewing of the brachial artery immediately proximal to the distal bypass anastomosis. The choice (ie, end-side or end-end) was dictated by which configuration looked the best and was easiest to perform although end-side anastomosis was a functional end-end one given the proximal ligation. Potential upper and lower extremity venous conduits for the DRIL were identified using ultrasound scan. Greater saphenous vein (≥3 mm) was used preferentially with the alternative choices dictated by availability or surgeon preference (arm vein > femoral vein > cadaveric vein > prosthetic). Every attempt was made to preserve any available suitable arm vein for future autogenous accesses. The venous conduits were used both in the reversed and nonreversed fashion with the choice dictated by the size match between the artery/vein when relevant (ie, larger vein end with larger artery).

Postoperative surveillance of the DRIL bypass included upper extremity arterial pressures/waveforms and duplex ultrasound scanning of the DRIL bypass as previously described for our lower extremity bypasses.[17] Surveillance was performed at 1 month, 3 months, 6 months, 9 months, 12 months, and then every 6 months thereafter. Additional imaging and/or treatment was performed for recurrent hand symptoms, significant decreases in the arterial pressures (ie, 15 mm Hg decrease in wrist pressure), and/or abnormal graft scans (ie, mean graft velocity <50 cm/s, maximum velocity ratio ≥3.5).[18]

Data analysis. Patient comorbidities were defined as any prior history of hypertension (any antihypertensive), coronary artery disease (angina, coronary artery bypass, percutaneous coronary angioplasty), peripheral vascular occlusive disease (claudication, ankle-brachial index <0.9, prior lower extremity revascularization), chronic obstructive pulmonary disease (smoking history >20 packs/year, abnormal pulmonary function tests, medication), diabetes mellitus (oral hypoglycemics, insulin), congestive heart failure (New York Heart Association Class II or greater), and cerebrovascular occlusive disease (transient ischemic attack, stroke, carotid endarterectomy/angioplasty), graft patency was objectively determined by ultrasound scan or arteriography scan. DRIL patency (primary, primary assisted, secondary) and patient survival were determined using the Kaplan-Meier method. Survival was confirmed by interrogating the National Death Index. The pre-operative and postoperative wrist/brachial indices (WBIs) and digital/brachial indices (DBIs) were compared with a paired *t* test and a *P* value < .05 was accepted as significant. All values,

Table I. Demographics, comorbidities, and access configuration

Demographics	
Age	59 ± 13
Gender (% male)	38%
Comorbidities	
End-stage renal disease	92%
Hypertension	74%
Diabetes mellitus	72%
Coronary artery disease	36%
Cerebrovascular occlusive disease	23%
Congestive heart failure	20%
Peripheral vascular occlusive disease	13%
Prior access-related hand ischemia	10%
Access configuration	
Brachiocephalic autogenous	46%
Brachiobasilic autogenous	31%
Brachioaxillary translocated femoral vein	20%
Brachioaxillary prosthetic	3%

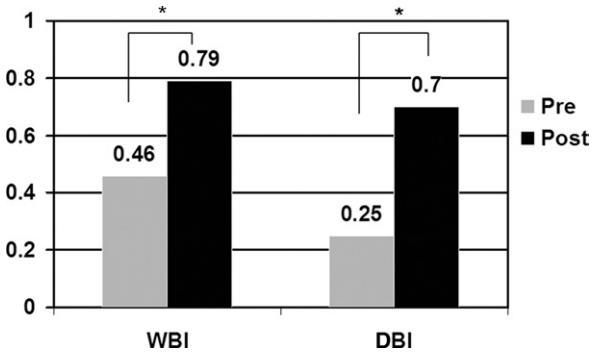

Fig 1. The mean preoperative (pre) and postoperative (post) wrist/brachial (WBI) and digital/brachial (DBI) indices are shown. Significant increases ($P < .05$) were noted for both indices after the DRIL procedure*.

unless otherwise specified, were reported as mean ± standard deviation.

RESULTS

A total of 77 patients with severe access-related hand ischemia were treated with a DRIL procedure (61 patients) or access ligation (16 patients) during the time course of the study. During this interval, 1519 access-related surgical procedures (exclusive of dialysis catheters) were performed including both new constructions and revisions. The incidence of severe access-related hand ischemia requiring ligation or DRIL was 6% among the new access procedures. A total of 64 DRIL procedures were performed in the 61 patients. The mean patient age was 59 ± 13 years and the majority was female, hypertensive, diabetic, and on hemodialysis (Table I). Notably, 10% had a prior episode of access-related hand ischemia. The brachial artery was the inflow source for all of the index access procedures with the brachiocephalic autogenous access configuration being the most common (Table I). A significant proportion of the patients had an autogenous brachioaxillary access using the translocated femoral/popliteal vein while only 2 patients had a prosthetic access. The primary ischemic symptoms that precipitated the DRIL procedures were pain (25%), paresthesia (34%), motor dysfunction (24%), and tissue loss (17%). A planned, pre-emptive DRIL (ie, simultaneous with the index access procedure) was performed in 5 patients because of a prior history of access-related hand ischemia (n = 3) and/or severe forearm arterial occlusive disease in conjunction with digital gangrene (n = 2). Noninvasive vascular laboratory studies were obtained to confirm the clinical diagnosis in approximately half of the patients (n = 33). The mean preoperative (ie, pre DRIL) WBI was 0.46 ± 0.19 and the mean DBI was 0.25 ± 0.23 with the latter used primarily for patients with noncompressible arteries at the wrist (Fig 1). The majority (83%) of the patients had an upper extremity arteriogram prior to their index access procedure or immediately prior to the DRIL. A significant arterial lesion was found on the arteriogram proximal to the brachial artery in 3 patients (subclavian stenosis – 2, brachial artery stenosis – 1) prior to the index access procedure and these were corrected to facilitate the procedure itself (ie, the index access). An additional 3 patients were found to have significant inflow lesions (subclavian stenosis – 2, brachial artery occlusion) during evaluation of their hand ischemia (ie, postoperative index access procedure); these were corrected at the time of the DRIL procedure.

The DRIL procedure was performed within 7 days of the index access procedure in almost half of the cases as dictated by the acuity/severity of the symptoms: <24 hours – 19%; 1 day < DRIL ≤7 days – 29%; 7 days < DRIL ≤30 days – 8%; >30 days – 44%. The greater saphenous vein was used as the conduit in the majority of cases (greater saphenous vein – 75%, basilic/cephalic vein – 19%, cadaveric vein – 5%, femoral vein – 2%, lesser saphenous vein – 2%). The in-hospital mortality rate after the DRIL was 3% with a single death resulting from withdrawal of hemodialysis and a second from a presumed arrhythmia. The non-fatal complication rate was 22% with the itemized breakdown including wound (14%), respiratory (3% - pneumonia, re-intubation), vascular (3% - lower extremity ischemia requiring amputation from femoral/saphenous vein harvest wounds; compartment syndrome), and cardiac (2% - arrhythmia) causes. The majority of the wound complications were mild although 2 patients required prolonged hospitalizations. The DRIL procedure relieved the precipitating ischemic symptoms in 78% of the cases (residual symptoms: paresthesia – 13%; pain – 5%; tissue loss – 4%; motor – 2%). Notably, the residual paresthesia and motor compromises were relatively minor with the latter associated only with very fine movements. Access ligation was required in a single patient with ongoing, severe pain despite a patent DRIL bypass and no identifiable, hemodynamically significant inflow lesion. All but 2 of the patients that presented with tissue loss were able to heal their wounds; the exceptions had severe forearm arterial occlusive disease as documented by arteriography. Both the WBIs and DBIs increased significantly ($P < .05$) with

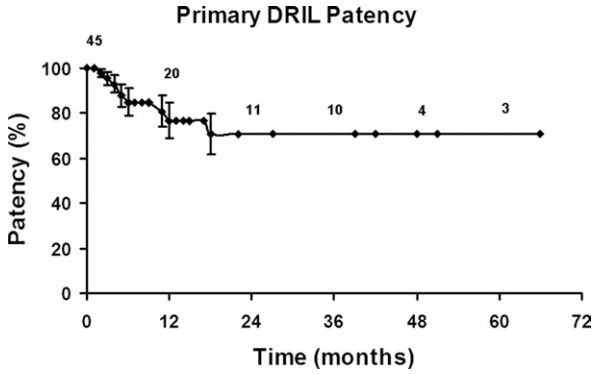

Fig 2. The Kaplan-Meier curve for the primary patency of the DRIL bypass is shown with the standard error bars. The standard errors were <10% throughout the time interval analyzed. The number of patients at risk are shown above the curve. The complete data can be found in Appendix I, online only.

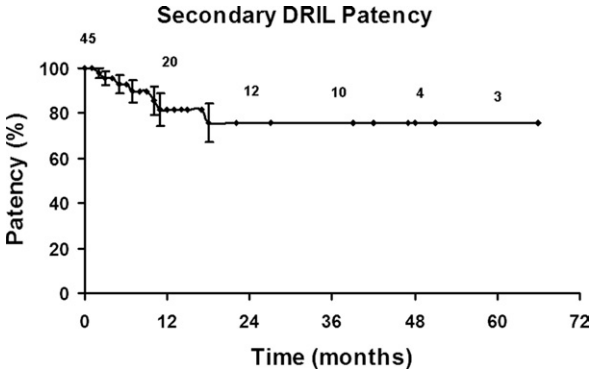

Fig 3. The Kaplan-Meier curve for the secondary patency of the DRIL bypass is shown with the standard error bars. The standard errors were <10% throughout the time interval analyzed. The number of patients at risk are shown above the curve. The complete data can be found in Appendix II, online only.

postoperative values of 0.79 ± 0.17 and 0.70 ± 0.25, respectively (Fig 1). This corresponded to a mean increase (preoperative vs postoperative) of 0.34 ± 0.26 for the WBIs and 0.41 ± 0.21 for the DBIs. The access maturation rate was 68% for the patients in which the DRIL procedure was performed early after the index access procedure (ie, prior to the index access every being cannulated for dialysis). All of the accesses in use at the time of the DRIL procedure were used throughout the peri-operative period without interruption.

The mean follow-up after the DRIL procedure was 12 ± 16 months (range, 0–66). The primary DRIL patency rates (± SEM) were 77 ± 8%, 74 ± 9%, and 71 ± 9% at 1 year, 3 years, and 5 years (Fig 2, Appendix I, online only), respectively, while the corresponding secondary patency rates were 81 ± 7%, 76 ± 9%, and 76 ± 9% (Fig 3, Appendix II, online only). The primary assisted and secondary patency rates were identical since all DRIL bypasses that thrombosed were abandoned. A total of 7 DRIL bypasses failed during follow-up. Three of the patients presented with recurrent symptoms (pain – 2, tissue loss) and underwent a redo DRIL bypass; one of which failed a second time requiring access ligation. Three other patients were asymptomatic after their DRIL bypass failed and did not required additional treatment. Notably, all 3 of the DRIL procedures performed with cadaveric vein thrombosed during follow-up. The patient survival after the DRIL procedure was 71 ± 6%, 59 ± 7%, and 33 ± 9% at 1 year, 3 years, and 5 years, respectively, with a median survival of 43 months (Fig 4, Appendix III, online only).

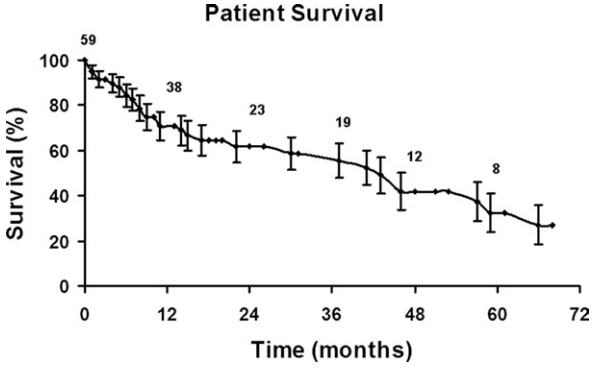

Fig 4. The Kaplan-Meier curve for the patient survival is shown with the standard error bars. The standard errors were <10% throughout the time interval analyzed. The number of patients at risk are shown above the curve. The complete data can be found in Appendix III, online only.

DISCUSSION

The results of our study further establish the benefits of the DRIL procedure as a safe, definitive treatment for access-related hand ischemia. Notably, it relieved the precipitating symptoms in the majority of patients with a success rate approaching 90% if the patients with residual paresthesia, presumably resulting from the initial ischemic injury to the nerve, were excluded. The clinical improvement was supported by the hemodynamic changes as measured by the WBIs and DBIs. Furthermore, the objectively documented, mid-term patency rates for the DRIL bypass were good and neither the patients' hands nor accesses appeared to be adversely affected. Perhaps not surprising, the overall survival for patients requiring a DRIL was poor, thereby suggesting that the long-term durability of the DRIL may be a secondary concern. The significance of these findings is further underscored by the fact that our study represents the largest published experience.

The results of our study are consistent with the other similar reports in the literature as summarized in Table II. Although the objectively documented follow-up is somewhat limited, DRIL patency, symptomatic relief, and access preservation all appear to be quite good, and, thereby, negate any reservations about the procedure (ie, concerns about graft patency, the viability of the hand, requisite need to ligate the brachial artery). The graft patency rates are not

Table II. Published DRIL series

Study	*Sample*	*DRIL patency*	*Symptom relief*	*Access preservation*	*Patient survival*
Haimov[10]	23	96% @ 2 yrs	100% - improved 83% - resolved	46% @ 2 yrs	NA
Katz[36]	5	100% (mean 7 mos)	83% - improved/resolved	100% (mean 7 mos)	NA
Stierli[37]	6	100% (6-24 mos)	100% - improved/resolved	100% (6-24 mos)	NA
Knox[11]	55	1° - 80% @ 4 yrs (life table)	90% - improved/resolved	71% @ 3 yrs (life table)	56% @ 4 yrs (life table)
Lazarides[12]	23	69% @ 1 yr	100% - resolved	NA	NA
Diehl[38]	13	83% @ 2 yrs	100% - improved 57% - resolved	71% @ 2 yrs	NA
Korzets[39]	9	100% (mean 12 mos)	100% -resolved	78% (mean 12 mos)	NA
Sessa[13]	18	94% (mean 16 mos)	100% - improved 73% - resolved	94% (mean 16 mos) mos)	61% (mean 16 mos)
Mwipatayi[40]	12	100% (median 4 mos)	83% -improved/resolved	NA	NA
Walz[14]	38	NA	67%	NA	NA
Current Study 2008.	64	1° - 71 ± 9 @ 5 yrs 2° - 76 ± 9 @ 5 yrs (Kaplan-Meier)	78% - resolved	New - 68% maturation Functional – 100% continued	33 ± 9 @ 5 yrs (Kaplan-Meier)

surprising given the relatively short length of the bypass and the requirement for adequate inflow. Admittedly, the collective DRIL experience is quite small given the 400,000 patients in the United States with end-stage renal disease[19,20] and an estimated 5% incidence of severe hand ischemia necessitating definitive treatment.[3-6]

The effectiveness of the DRIL procedure is predicated upon its ability to reverse the hemodynamic changes associated with the creation of an arteriovenous hemodialysis access. The construction of an access can cause a decrease in the arterial pressure and blood flow distal to the access anastomosis. The normal compensatory responses include an increase in the cardiac output and arterial vasodilation. When these compensatory mechanisms are inadequate, the hand may become ischemic. Predictably, a hemodynamically significant inflow (eg, subclavian artery) or outflow (eg, forearm radial/ulnar) lesion can exacerbate the initial hemodynamic changes and further inhibit the compensatory responses. Illig et al[21] measured the mean pressures over the course of the brachial artery after a series of access procedures based on the distal brachial artery (ie, near the antecubital fossa). They reported that the mean pressure decreased from 102 mm Hg proximally to 47 mm Hg at the anastomosis. This gradient did not change after construction of the DRIL, however, the forearm perfusion pressure (ie, the pressure within the DRIL bypass) was found to be identical to the proximal brachial artery. Furthermore, compression of the access did not change the distal perfusion pressures after the DRIL. These hemodynamic changes support the clinical observation that the proximal DRIL anastomosis should be sited ≥7 cm from the access anastomosis (ie, prior to the brachial artery pressure gradient). Interestingly, Gradman and Pozrikidis[22] developed a model to analyze the hemodynamic changes associated with the various treatments for access-related hand ischemia and concluded that the DRIL was the most effective.

A variety of remedial treatments have been described for access-related hand ischemia.[23-25] Clearly, the ultimate objectives are to salvage hand function and preserve the access (if at all possible). It is our impression that the DRIL procedure achieves these objectives most effectively and it is relatively simple to perform. However, there are specific scenarios where the other approaches may be useful. Access ligation is effective, and, theoretically, restores the hand perfusion to the pre-access state at the expense of the access. For all practical purposes, it is our second choice for patients that are not DRIL candidates. Interestingly, the patient survival in the subset of our patients who underwent ligation was very poor (median survival 16 months – data not shown). Despite a recent resurgence,[26,27] the strategies to limit the flow through the access using some form of "banding" procedure (ie, lengthening the access, narrowing the access, narrowing the anastomosis) have been relatively unsuccessful. The fundamental problem is the inability to regulate the access flow to a level that improves the perfusion of the hand while sustaining dialysis and a patent access. Both the distal revascularization without ligation[28] and the proximalization of the arterial inflow[25] (eg, resiting the brachial access anastomosis onto the axillary artery) may restore adequate hand perfusion, but they may not be as effective as the DRIL procedure from a hemodynamic standpoint.[22] Minion et al[24] have described converting a brachial artery-based autogenous access to a radial artery based one using an interposition saphenous vein (RUDI – revision using distal inflow). However, the overall success rate for radial artery based access procedures in women, the elderly, and diabetics is fairly poor.[29] Finally, the identification and correction of arterial inflow lesions has been reported to be effective.[30,31] However, our experience would suggest that the incidence of inflow lesions may not be as high as suggested by the literature and that treating the inflow lesion alone may not be sufficient.

The DRIL procedure represents only one component of a broader strategy to reduce the incidence of hand ischemia and avoid its long-term sequelae. Contrary to some reports,[32] it is a common problem and should be considered/anticipated pre-operatively in certain subsets of

patients. The risk factors are fairly extensive and include advanced age, female gender, diabetes, peripheral arterial occlusive disease, large conduits (ie, femoral/popliteal vein), and multiple prior procedures.[4,6-9] Additionally, it has been our anecdotal impression that a history of access-related hand ischemia is the strongest predictor of future events. Noninvasive imaging has proven invaluable to help select the most appropriate arterial inflow site and help identify any significant proximal lesions. We have adopted a selective approach to preoperative invasive imaging and feel that it is worthwhile given the fact that 40% of the patients had some type of abnormality on arteriography or venography during the prospective validation of our algorithm.[15] The operative procedure itself can also be modified in patients at risk for ischemia. Specifically, the translocated femoral/popliteal vein access should likely be avoided in patients at risk for hand ischemia. All arterial inflow lesions can be corrected simultaneously and a variety of less common and/or exotic access configurations have been described to reduce the incidence of ischemia including siting the anastomosis on the axillary artery,[25] a branch of the axillary artery[33] or the proximal radial artery.[34] Indeed, the preemptive DRIL represents the most aggressive/invasive approach to reduce the incidence of hand ischemia.[35] A plan should be generated at the time of index access procedure to address the hand ischemia when/if it becomes problematic and we frequently survey the upper and lower extremity veins during the pre-operative evaluation to identify a potential DRIL conduit. Notably, all three of the DRIL procedures performed with cadaveric conduits failed, thereby, suggesting that they are a poor alternative to autogenous vein. Patients should be educated about the symptoms associated with hand ischemia and engaged in their own health care given the fact that only half of the ischemic events necessitating DRIL occurred during the first month after the index procedure. Lastly, all hand complaints after an access procedure should be assumed to be secondary to ischemia despite equivocal findings on physical examination and/or noninvasive testing.

The current study has several limitations inherent to its retrospective design. The patients were fairly highly selected. Specifically, the index access configuration was selected based upon the results of the noninvasive/invasive imaging using defined criteria to identify the best artery/vein combination for a successful access. Theoretically, this precluded siting the anastomosis distal to a hemodynamically significant lesion and reduced the overall incidence of hand ischemia. Although we would contend that this is optimal, our reported incidence of hand ischemia and the relevance of arterial inflow lesions may be lower than other centers. Our follow-up was only fair despite the standard errors (<10%) reported in the patency/survival curves and it is likely that the actual values may not be as good as the estimated values. We have adopted an aggressive surveillance protocol for the DRIL patients, but it is often difficult to convince the patients to comply with the follow-up regimen. Lastly, the long-term patency rates for the accesses themselves are not well documented since we generally defer their overall management and surveillance to the responsible nephrologists after they are suitable for cannulation.

In conclusion, the DRIL procedure safely and effectively relieves the symptoms of severe access-related hand ischemia while preserving the access. The mid-term results suggest that the DRIL bypasses are durable although long-term graft surveillance may be justified given the observed graft failures.

AUTHOR CONTRIBUTIONS

Conception and design: TH, MB
Analysis and interpretation: TH, MB, WL, JS
Data collection: TH, MH
Writing the article: TH, JS
Critical revision of the article: TH, MB, WL, JS
Final approval of the article: TH, MH, WL, JS
Statistical analysis: TH, WL
Obtained funding: Not applicable
Overall responsibility: TH

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DISCUSSION

Dr. David L. Cull. I would like to congratulate the authors on this timely study and their well written manuscript. The University of Florida group has a legacy of making significant contributions to the vascular access literature and this paper continues that legacy.

Dr. Huber and colleagues have presented the largest series of DRIL procedures reported to date in the literature. At the University of Florida, 6% of new AV access procedures performed during the period of this study had a DRIL procedure for access-related steal. In Greenville, we too have a very busy vascular access practice, and I have no doubt that the incidence of steal in our practice parallels that of Dr. Huber's. However, their experience with the DRIL procedure for the treatment of steal far eclipses our experience. As I read their manuscript, the differences between our approaches to access-related steal becomes apparent. Dr. Huber's group treats access-related steal early and aggressively with a DRIL procedure. In his series, nearly 50% of the DRIL procedures were performed within 1 week of the index AV access procedure. Thirty-four percent of patients underwent a DRIL for the symptom of paresthesia alone. Five patients in this series had a preemptive DRIL procedure prior to fistula creation.

I have considered the DRIL procedure to be an effective operation for the treatment of steal but an operation that can be quite challenging particularly in obese patients and in cases where the AV fistula anastomosis is located close to the terminus of the brachial artery. Furthermore, I have been concerned about the long-term patency of the brachial artery bypass and by the fact that symptom relief is not assured after the procedure. Finally, as noted in Dr. Huber's study, many of these patients have a limited life expectancy. Particularly for those patients who have severe distal arterial occlusive disease who are at the highest risk for steal. Given these concerns, I have approached patients with access-related steal more cautiously and have reserved the DRIL procedure for patients who have functioning fistulas who present with digital gangrene, motor dysfunction, or significant pain. For patients who present with paresthesia soon after fistula creation, I have found that for many

the symptoms will improve with time. In patients who have severe steal immediately after AV access creation, I try to determine if the fistula is likely to mature and if salvage of the fistula is worth the effort. If maturation of the fistula is in doubt, I generally ligate the fistula and move to another site. In the current series, for those patients who had an early DRIL procedure, 32% of the fistulae never matured.

Now that you have provided us that mid-term outcome for the DRIL procedure, I would like you to help me put these results into perspective and provide me with guidance as to when I should perform a DRIL procedure in my patients with access-related steal? In other words, should I expand my current approach to access-related steal? I appreciate the opportunity to discuss this paper.

Dr Huber. Despite your impressions, I would contend that our practices are almost identical. Although a third of the procedures were performed for paresthesia, I would say that these episodes of paresthesia were significant in the sense of acute extremity ischemia. It is not paresthesia in the sense that my hand bothers me a little bit, but rather truly limb-threatening ischemia in which we are forced to do something. Many of the patients develop hand ischemia on the evening of the procedure and I can tell you that my partners and I wouldn't be driving back to the hospital in the middle of the night to do the DRIL procedure unless it was absolutely necessary. Our incidence of severe hand ischemia is essentially the same as everyone else's in the literature with a realistic number being between 5 – 10% for brachial artery based procedures. Concurrent with these 64 DRIL procedures, we did 17 access ligations for this same problem. We have taken a fairly aggressive approach to revascularization and I would say that it is probably justified. There is a subset of patients that have preemptive DRILs, and perhaps we are a couple of standard deviations from the norm in these instances, but those were people that truly have terminal access problems and had no other access choice other than a catheter. I think we all feel the pressures about committing patients to long-term catheters and the concept that we will just ligate the access and move on hasn't worked in our practice. I would say, albeit somewhat anecdotal, that the incidence of hand ischemia during subsequent access procedures in someone who has an episode of hand ischemia is 100%. Accordingly, I would contend you have to have a plan, perhaps even a preemptive plan, about how you are going to address the inevitable hand ischemia on the contralateral extremity in this subset of patients. We believe that the DRIL procedure is very effective. The morbidity and mortality are generally acceptable, the long-term patency rate is great and it effectively preserves the access and reverses the ischemia. Unfortunately, patient survival is poor, thereby suggesting that access-related hand ischemia is a marker for a particularly bad patient outcome.

Appendix I (online only). DRIL primary patency rates Kaplan Meier

Time (mos)	*Subjects at risk*	*Secondary patency (%)*	*SE*
0	45	100	0
1	45	100	0
2	44	98	1
3	42	95	3
4	40	93	4
5	35	88	5
6	31	85	6
7	27	85	6
8	26	85	6
9	24	85	6
11	21	81	7
12	20	77	8
13	18	77	8
14	17	77	8
15	15	77	8
17	14	77	8
18	13	71	9
22	11	71	9
27	10	71	9
39	9	71	9
42	6	71	9
48	4	71	9
51	3	71	9
66	1	71	9

Appendix II (online only). DRIL secondary primary patency rates Kaplan Meier

Time (mos)	*Subjects at risk*	*Secondary patency (%)*	*SE*
0	45	100	0
1	45	100	0
2	44	98	2
3	42	95	3
4	40	95	3
5	36	93	4
6	32	93	4
7	29	90	5
8	27	90	5
9	25	90	5
10	22	85	6
11	21	81	7
12	20	81	7
13	19	81	7
14	18	81	7
15	16	81	7
17	15	81	7
18	14	76	9
22	12	76	9
27	11	76	9
39	10	76	9
42	7	76	9
47	5	76	9
48	4	76	9
51	3	76	9
66	1	76	9

Appendix III (online only). Patient survival Kaplan Meier

Time (mos)	*Subjects at risk*	*Secondary patency (%)*	*SE*
0	59	100	0
1	59	95	3
2	56	92	4
3	52	92	4
4	51	90	4
5	49	88	4
6	48	84	5
7	46	82	5
8	43	79	6
9	41	75	6
10	39	75	6
11	38	71	6
13	35	71	6
14	34	69	6
15	31	67	7
17	30	65	7
18	27	64	7
19	26	64	7
20	25	64	7
22	24	62	7
24	23	62	7
26	22	62	7
30	21	59	7
31	19	59	7
37	18	55	7
41	17	52	8
43	16	49	8
46	14	42	8
48	12	42	8
51	11	42	8
53	10	42	8
57	9	37	8
59	8	33	9
61	7	33	9
66	6	27	9
68	5	27	9
73	4	27	9
74	3	18	9
78	2	18	9
79	1	18	9